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Research Paper

LICHENS SPECIES DIVERSITY AS AIR QUALITY BIOINDICATOR IN GUNUNG BIBI FOREST, MOUNT MERAPI NATIONAL PARK

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ARTICLE HIGLIGHTS

- The study identified 36 lichen species from 14 different families.
- The lichen composition differed between stations, indicating disparities in air quality.
- Station II (1600-1700 masl) had better air quality than Station I (1600-1700 masl), which had a higher diversity index value and more lichen coverage.
- Nitrogen emissions from farming may reduce the non-nitrophilic lichen diversity and abundance.
- The diversity and abundance of lichen is affected by air temperature, humidity, light intensity, and the type of bark.

Article Information

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ABSTRACT

Mount Merapi ecosystem is distinguished by its considerable biodiversity potential, leading to its designation as a national park with main function to protect its unique ecological characteristics. A notable example of Mount Merapi ecosystem is Gunung Bibi Forest, which has been designated as a Sanctuary Zone within Mount Merapi National Park, having primary objectives of biodiversity conservation, habitat preservation, and ecosystem protection. Nevertheless, Gunung Bibi Forest is susceptible to the repercussions of volcanic eruptions and the pressure of agricultural activities from the surrounding area, which may potentially impact its air quality. Given the geographical area of the forest, the most efficient method for air quality monitoring is by using lichens species diversity as bioindicator. This study aimed to analyze the relationship between lichen species diversity and air quality in Gunung Bibi Forest area of Mount Merapi National Park, including all influencing factors. Data collection was carried out by dividing the area into two research stations based on altitude, using a purposive sampling method followed with data analyses to calculate lichen abundance, lichens thallus coverage area, and Shannon-Wiener Diversity Index. This study found 36 lichen species belonging to 13 different families. The lichen species composition at the two stations were different, indicating disparities in air quality between the two stations. Station II (1,600 - 1,700 masl) exhibited indications of a better air quality in comparison to Station I (1,500 - 1,600 masl), which was distinguished by a higher diversity index value, as well as a greater lichens thallus coverage area. The difference in air quality between the two research stations might have been caused by nitrogen emissions from agricultural activities, which limited the diversity and abundance of non-nitrophilic lichens species. Environmental factors affecting lichens species diversity and abundance were air temperature, humidity, light intensity, and bark type of lichen substrate.

Keywords: air pollution, bioindicator, lichens, Mount Merapi National Park, Shannon-Wiener Index

INTRODUCTION

Mount Merapi is one of tropical rainforest ecosystems in Indonesia, characterized by its high biodiversity, which is considered to be a significant source of germplasm (Wijayati & Rijanta 2020). The unique characteristics of Mount Merapi ecosystem has led this area to be designated as a national park, with the objective of protecting its unique ecological features. Mount Merapi National Park (MMNP) was established in 2014 based on the Minister of Forestry Decree No. SK.3627/Menhut-VII/KUH/2014, with one of the main objectives to protect the habitat and biodiversity of flora and fauna living in the area (Wijayati & Rijanta 2020).

However, Mount Merapi is one of the most active volcanoes in the world, with a short eruption period of 2 - 7 years (Wismaya 2016). The high volcanic activity of Mount Merapi can have various impacts on the surrounding environment. Volcanic activity can release ash and gases into the atmosphere, which can be a source of air pollution. This volcanic ash and gas can affect the biogeochemical cycles of carbon, sulphur, and halogens in the ecosystem (Delmelle *et al.* 2015). This is exacerbated by anthropogenic activities emanating from the slopes of Mount Merapi. Therefore, air pollution monitoring is becoming increasingly important.

To monitor environmental pollution, organisms, such as lichens, can be used as bioindicator to conduct biomonitoring. Lichen is an organism resulting from the mutual symbiosis between algae and fungi (Untari 2024). Lichen obtains its nutrients from the surrounding air, so it is sensitive to the quality of the surrounding air, therefore, can be used as a bioindicator organism for monitoring air quality (Bukabayeva *et al.* 2023). Lichen is a long-lived and slow-growing organism with an unchanging morphology, no roots and no protective structure, so it can passively absorb substances from the atmosphere throughout its life cycle (Zarabska-Bożejewicz 2020).

Lichens can be used as bioindicators of air pollution in the form of heavy metals, organic compounds, and even radioactive elements (Bukabayeva *et al.* 2023). Monitoring using lichens is simple and informative because it can assess the ecological state of the environment along with the response of the organisms, it allows for a wider study area, and it is more effective and cost-effective (Matos *et al.* 2019).

This research was carried out in Gunung Bibi Forest of Mount Merapi National Park. Administratively, Gunung Bibi is located in Wonodoyo Village, Cepogo Subdistrict, Boyolali Regency, Central Java Province, Indonesia. Gunung Bibi Forest is included in the Sanctuary Zone, with functions to protect biodiversity, habitats, and ecosystems in the Mount Merapi National Park area. Therefore, ecosystems in the core zone are unaffected by human influence and anthropogenic activities. As an area included in the core zone, Gunung Bibi Forest has a high biodiversity value which is typical of the Mount Merapi ecosystem (Wijayati & Rijanta 2020).

Despite the highly valued biodiversity, Gunung Bibi Forest is located in the area mostly affected by the eruption of Mount Merapi, with an air quality index category classified as unhealthy (Nugroho *et al.* 2023), and surrounded by areas having a high level of agricultural activities, predominantly involving agriculture and cattle farming, which serve as the primary means of subsistence for the local community (BPS 2023). Both conditions have the potential to affect the air quality on Gunung Bibi, therefore, air quality monitoring is recommended.

Given the remote location of Gunung Bibi, characterized by rugged topography and limited access to power supplies, the utilization of lichen as bioindicator for air quality monitoring could offer certain advantages in terms of efficiency when compared with instrumented monitoring techniques (Blett *et al.* 2003). As demonstrated by the lichen data collected, there are regions of particular concern, which make the data useful for further, more extensive and instrumented monitoring studies (Blett *et al.* 2003).

Notwithstanding the rich biodiversity of Gunung Bibi, there has never been a comprehensive study of lichens diversity as a bioindicator in this area. Previous research on lichens in Gunung Bibi was limited to the identification of lichens species, such as the initial report on corticolous lichens by Susilawati (2013) and a subsequent study on the characterization of fruticose and foliose lichens by Susilawati (2017). Similar studies in other regions have demonstrated that lichens diversity is closely related to air pollution levels, particularly the presence of sulfur, nitrogen, and atmospheric heavy metals from both natural and anthropogenic activities (Agnan 2017; Zarabska-Borăilescu 2020; Bukabayeva 2023). However, no report has yet been found that addressed the question of a possible correlation between diversity in lichens samples and air quality in the studied area, to establish the possibility of lichens as air quality bioindicator. Therefore, to answer this question, a research was conducted to analyze the relationship between lichens species diversity and air quality in Gunung Bibi Forest of Mount Merapi National Park, and the factors influencing the air quality. The findings from this research are expected to provide deeper insights into the potential of lichens as environmental bioindicators in conservation areas, while serving as a basis for monitoring strategies and mitigating the impacts of air pollution in this region.

MATERIALS AND METHODS

Study Area

This study was conducted in Gunung Bibi Forest area, located in the Musuk-Cepogo Region National Park Management Resort, Mount Merapi National Park. The study area (Fig. 1) started from the forest entrance of Gunung Bibi in Kedung Pedut, located at 7°31'17.8968" S and 110°28'20.8308" E with an altitude of 1,514 meters above sea level (masl).

Data Collection

Data collection was carried out using the cruising method and purposive sampling at two research stations based on altitude. Station I was located at an altitude of 1,500 – 1,600 masl adjacent to agricultural areas, while Station II was located at 1,600 – 1,700 masl relatively further away from agricultural areas. Data on lichens diversity were collected on host trees with a diameter of more than 15 cm. The host tree sites were geotagged with a Garmin 64s GPS (Garmin, USA) to determine the coordinates of the sites.

Lichens abundance data were collected by placing a 20 x 20 cm clear plastic plot on the side of the trunk of the host tree with the highest lichens coverage area, approximately 1 m above the ground. Lichens found in the plots were counted for abundance, and lichens silhouettes were drawn to calculate thallus coverage area. Environmental parameters recorded included air temperature, humidity and light intensity. The host trees on which the lichens were growing were also recorded and identified. Lichens found were then documented and collected for identification in the laboratory.

Identification was based on morphological, anatomical and secondary metabolite analysis using the spot test method of Hale (1961). The spot test was performed by making a cross-section of the lichens thallus and adding K (10% Potassium Hydroxide (KOH) in aquadest), P (5% Paraphenylenediamine ($C_6H_4(NH_2)_2$) in 95% alcohol) and C (10% Calcium Hypoclorite ($Ca(ClO)_2$) in aquadest) reagents. Color changes in the medulla layer were observed under a stereomicroscope. The identification of the studied lichens specimens was conducted using reference materials, including the Key to the Lichen Genera of Bogor, Cibodas and Singapore (Sipman 2003) and Macrolichens of the Pacific Northwest (McCune & Geiser 2009). Additional sources consulted included the Consortium of Lichen Herbaria website (www.lichenportal.org), the British Lichen Society (www.britishlichensociety.org.uk), and other relevant publications.

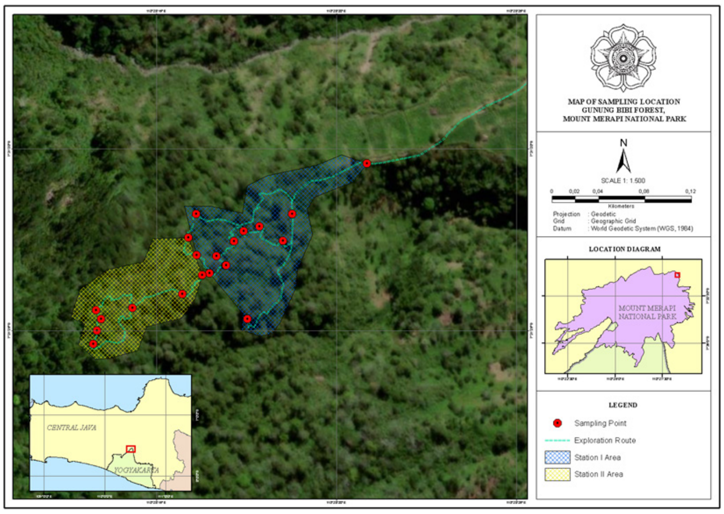

Figure 1 Study area in the Gunung Bibi Forest, Mount Merapi National Park

Data Analysis

The data obtained were analyzed to obtain the Importance Value Index (IVI) by calculating the values of Relative Frequency (RF), Relative Density (DR), and Relative Dominance (RDo) according to Garrido *et al.* (2021) by the following formula.

$$\text{Relative Frequency (RF)} = \frac{\text{number of plot in which lichen species occurred}}{\text{total number of plot}} \quad \ldots(1)$$

$$\text{Relative Density (RD)} = \frac{\text{number of lichen colony}}{\text{total number of lichen colony}} \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$\text{Relative Dominance (RDom)} = \frac{\text{thallus surface area of lichen species}}{\text{total thallus surface area of all lichens species}} \quad ..(3)$$

The species diversity was analyzed using the Shannon-Wiener Diversity Index to compare lichens species diversity at each station. The Shannon-Wiener Diversity Index was analyzed according to Yulianti *et al.* (2022) by the following formula.

$$H' = -\sum (ni/N).\log(ni/N) \quad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

where:

H' = Shannon-Wiener diversity index

Ni = Number of individuals of a certain species

N = Total number of individuals of all species

The value of the Shannon-Wiener Diversity Index is categorized into three categories as follows (Yulianti *et al.* 2022).

H ≤ 1 = Low species diversity in the area

H' 1 ≤ H' ≤ 3 = Medium species diversity in the area

H' ≥ 3 = High species diversity in the area

The calculation of lichens thallus area was performed using Image J 1.54g software (National Institutes of Health, USA) which automatically measured the area of a photographic image by counting the number of pixels per area (Aragón-Sánchez *et al.* 2017). Data processing and visualization were performed using Microsoft Excel software (Microsoft, USA).

RESULTS AND DISCUSSION

A total of 61 individual trees were sampled for lichens species at the 2 research stations, resulting in a total of 36 lichen species from 13 different families (Table 1).

Parmeliaceae was the predominant family, with a total of 11 species, followed by Pertusariaceae (5 species), Physciaceae (4 species), Stereocaulaceae (3 species), Lecanoraceae (2 species), Graphidaceae (2 species), Phlyctidaceae (2 species), Monoblastiaceae (1 species), Chrysotrichaceae (1 species), Arthoniaceae (1 species), Collemataceae (1 species), Megalosporaceae (1 species), and Ramalinaceae (1 species).

Parmeliaceae is the most diverse group of lichens in the world, consisting of 2,765 species and 77 genera (Lücking *et al.* 2017), with a wide distribution. A study by Karmacharya *et al.* (2022) showed similar results that Parmeliaceae is also the most dominant family in the Kathmandu Valley area, consisting of 8 genera and 20 species.

In our study, the species that exhibited the highest Importance Value Index (IVI) values at Station I were Graphis scripta (72.01), Phlyctis argena (69.42), and Flavoparmelia caperata (34.16). Conversely, the highest IVI values at Station II were observed in Phlyctis argena (80.56), Cryptothecia striata (19.00), and Parmotrema perlatum (18.67). This finding indicated clear disparities in the prevalent lichens species at the two research stations, suggesting variations in lichens composition between the stations. Furthermore, G. scripta and P. argena are cosmopolitan lichens that demonstrate a high level of resistance to various environmental conditions, including atmospheric metal pollution (Agnan *et al.* 2017), thus explaining their dominance at both Station I and Station II. Both species also have a broad global distribution, G. scripta (Fig. 2a) has a distribution in tropical to subtropical areas, while P. argena (Fig 2b.) has a distribution in Africa, Europe, North America, and Asia (Nash *et al.* 2002).

Table 1 Diversity and abundance of lichens species found at the research site

Location	Taxonomic category	Number of individual	Number of colonies	Lichens thallus coverage area (cm^2)	IVI
Station I	Family Parmeliaceae				
	Hypotrachyna afrorevoluta (Krog & Swinscow) Krog & Swinscow	1	1	15.33	3.02
	Flavoparmelia caperata (L.) Hale	5	28	252.74	34.16
	Parmelina tiliacea (Hoffm.) Hale	1	4	66.17	6.36
	Parmotrema perlatum (Huds.) M.Choisy	4	14	395.72	28.22
	Punctelia perreticulata (Räsänen) G.Wilh. & Ladd	1	3	33.26	4.76
	Ramalina fraxinea (L.) Ach.	1	1	25.35	3.33
	Usnea glabrescens (Nyl. ex Vain.) Vain.	2	2	5.07	5.27
	Usnea subfloridana Stirt.	2	2	36.67	6.23
	Family Stereocaulaceae				
	Lepraria elobata Tønsberg	2	12	304.74	20.34
	Lepraria incana (L.) Ach.	1	1	25.87	3.34
	Lepraria lobificans Nyl.	2	2	81.77	7.60
	Family Pertusariaceae				
	Pertusaria amara (Ach.) Nyl.	1	1	88.04	5.24
	Pertusaria multipuncta (Turner) Nyl.	1	1	37.50	3.70
	Family Physciaceae				
	Heterodermia diademata (Taylor) D.D.Awasthi	1	3	126.19	7.59
	Physcia sorediosa (Vain.) Lynge	1	1	11.43	2.90
	Family Lecanoraceae				
	Lecanora barkmaniana Aptroot & Herk	1	1	34.97	3.62
	Lecanora compallens Herk & Aptroot	1	1	3.33	2.66
	Family Graphidaceae				
	Graphis scripta (L.) Ach.	9	53	749.53	72.01
	Family Phlyctidaceae				
	Phlyctis argena (Ach.) Flot.	12	32	881.94	69.42
	Family Chrysotrichaceae				
	Chrysothrix candelaris (L.) J.R.Laundon	2	5	110.29	10.25
	Total	**51**	**168**	**3,285.9**	

Location	Taxonomic category	# of individual	Number of colonies	Lichens thallus coverage area (cm^2)	IVI
Station II	Family Parmeliaceae				
	Hypotrachyna britannica (D.Hawksw. & P.James) Coppins	2	3	51.79	6.54
	Hypotrachyna revoluta (Flörke) Hale	1	1	43.01	3.32
	Flavoparmelia caperata (L.) Hale	3	4	146.01	11.24
	Parmeliopsis ambigua (Hoffm.) Nyl.	1	1	20.23	2.71
	Parmotrema perlatum (Huds.) M.Choisy	5	5	303.27	19.00
	Parmotrema xanthinum (Müll.Arg.) Hale	1	7	46.33	8.29
	Punctelia perreticulata (Räsänen) G.Wilh. & Ladd	1	4	33.94	5.52
	Ramalina fraxinea (L.) Ach.	2	2	4.78	4.46
	Family Pertusariaceae				
	Pertusaria albescens (Huds.) M.Choisy & Werner	3	3	142.09	10.32
	Pertusaria amara (Ach.) Nyl.	1	1	11.50	2.47
	Pertusaria leioplaca (Ach.) DC.	1	1	25.03	2.84
	Pertusaria multipuncta (Turner) Nyl.	3	4	80.32	9.47
	Pertusaria pertusa (L.) Tuck.	3	3	215.98	12.32
	Family Physciaceae				
	Heterodermia diademata (Taylor) D.D.Awasthi	4	6	111.30	13.28
	Physcia adscendens H.Olivier	1	1	6.24	2.33
	Physcia stellaris (L.) Nyl.	2	8	119.33	12.42
	Family Stereocaulaceae				
	Lepraria elobata Tønsberg	1	1	21.89	2.75
	Lepraria incana (L.) Ach.	3	1	247.53	11.54
	Lepraria lobificans Nyl.	1	1	90.21	4.60
	Family Graphidaceae				
	Diorygma hieroglyphicum (Pers.) Staiger & Kalb	1	1	4.12	2.28
	Graphis scripta (L.) Ach.	4	5	156.54	13.69
	Family Lecanoraceae				
	Lecanora compallens Herk & Aptroot	2	6	103.13	10.36
	Family Phlyctidaceae				
	Phlyctis argena (Ach.) Flot.	17	31	1,201.03	80.56
	Phlyctis boliviensis Nyl.	1	1	93.88	4.70
	Family Arthoniaceae				
	Cryptothecia striata	4	8	250.63	18.67
	Family Chrysotrichaceae				
	Chrysothrix candelaris G.Thor	2	7	136.61	12.08
	Family Collemataceae				
	Collema subflaccidum Degel.	1	1	12.48	2.50
	Family Fuscideaceae				
	Fuscidea lightfootii (Sm.) Coppins & P.James	1	1	13.58	2.53
	Family Megalosporaceae				
	Megalospora atrorubicans (Nyl.) Zahlbr.	1	1	4.12	2.28
	Family Monoblastiaceae				
	Anisomeridium biforme (Schaer.) R.C.Harris	1	4	11.84	4.92
	Total	**74**	**123**	**3,708.7**	

Note: IVI = Importance Value Index.

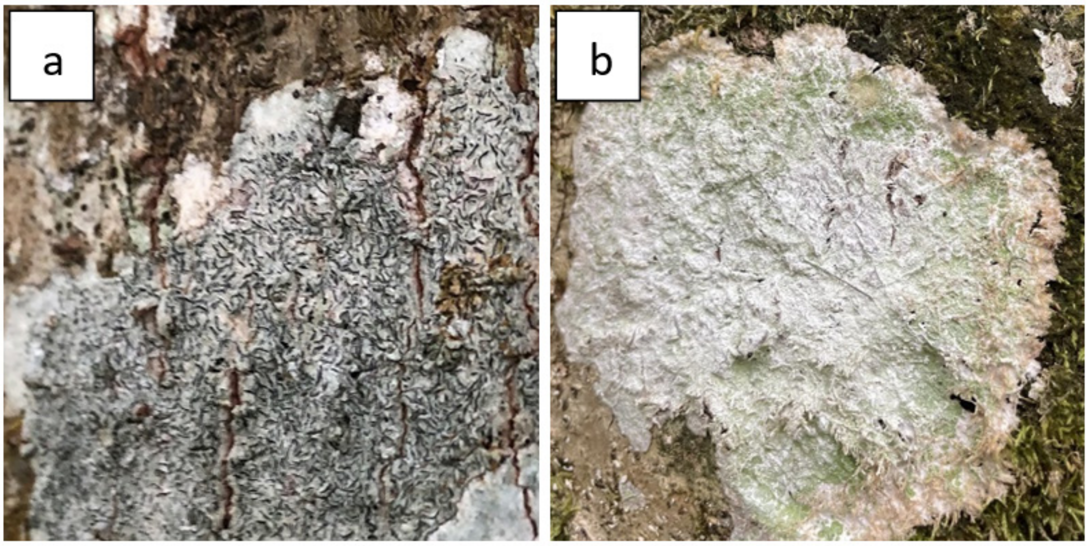

Figure 2 Species with the highest IVI at each station

Notes: a = *Graphis scripta* (Station I); b = *Phlyctis argena* (Station II)

Station I recorded 20 lichens species from 8 different families, while Station II recorded 30 lichens species from 13 different families (Table 1). The Shannon-Wiener Diversity Index showed that Station I had a level of lichens diversity in the "medium" category with a value of 2.557. Station II, on the other hand, had a level of lichens diversity in the "high" category with a value of 3.003. The observed discrepancy in the diversity of lichens samples collected from the two stations indicated a potential difference in the quality of ambient air at these locations.

In the early stages of exposure to air pollution, there will be an increase in the concentration of pollutants in the lichens thallus; as the pollution levels increase lichens may disappear completely, creating a condition known as 'lichens desert' (Bukabayeva *et al.* 2023). Therefore, the higher the air pollution in an environment, the lower the lichens diversity found in the environment (Muvidha 2020).

In this particular instance, Station II exhibited a better air quality, as proven by the higher level of lichens diversity compared to that at Station I. In addition, Station I was characterized by a greater total number of lichens colonies; however, it has a comparatively lower lichens thallus coverage area compared to Station II (Table 1).

Lichens thallus coverage area can be used as an indicator to assess the suitability of environmental conditions in which lichens live. Good environmental conditions allow lichens to grow optimally, so that lichens can be found intact with a large area of thallus coverage. The accumulation of air pollution in the thallus of lichens causes physiological and morphological changes in the lichens, resulting in a decrease in thallus coverage area and even fragmentation of originally intact thallus parts (Nasriyati *et al.* 2018). The reduction in thallus coverage area is one of the lichens responses to ambient air pollution (Nasriyati *et al.* 2018). This result strengthened the previous indication that Station II had a better air quality than that at Station I, which was indicated by higher lichens thallus coverage area at Station II.

The poor air quality at Station I may have been caused by anthropogenic activities since the location of Station I is closer to residential areas and the agricultural land of the residents, which heightened the impact of agricultural activities to air quality at Station I. Agricultural activities, such as the use of organic and mineral fertilizers and the burning of organic materials, can release nitrogen compounds into the air, for example in the form of ammonia (NH_3), which can increase the pH of tree bark when deposited (Zarabska-Bożejewicz 2020).

Furthermore, high atmospheric nitrogen levels lead to changes in lichens diversity and abundance, such as an increase in nitrophilic lichens species and a decrease in the abundance of non-nitrophilic species (Zarabska-Bożejewicz 2020). In non-nitrophilic species, excessive nitrogen exposure leads to a decrease in chlorophyll A and ergosterol (Zarabska-Bożejewicz 2020).

Most of the people in Cepogo Subdistrict work as farmers. According to BPS data (2023), Cepogo Subdistrict is the subdistrict with the largest number of individual agricultural businesses in Boyolali District, which includes food crops, horticulture, plantations, and livestock farming.

As for the livestock subsector, there are a total of 9,478 households that raise livestock, including beef cattle, dairy cattle, and goats (BPS 2023), which makes Cepogo Subdistrict one of the largest contributors to cattle farming in Boyolali Regency. In the management of livestock waste, there are still farmers who do not treat the wastes, but directly dispose the wastes in the backyard of the house, in the river around the settlements, or even directly dispose the wastes in their gardens and fields without prior treatment (Pertiwi *et al.* 2022). The activity of disposing agricultural wastes without treatment can produce gas emissions that can pollute the environment, such as ammonia (NH_3), hydrogen sulfide (H_2S), carbon dioxide (CO_2), and methane gas (CH_4) (Pertiwi *et al.* 2022).

Aerobic organic wastes treatment (composting) is one of the sources of NH_3 emissions (Zarabska-Bozejewicz 2020). The deposition rate of ammonia (NH_3) is rapid, causing most of ammonia to be easily distributed close to the emission source. About 10% of NH_3 can be found within 100 m of the emission source, and when dissolved in water and ionized to NH_4^+, ammonia can be transported as far as 1,000 km (Zarabska-Bozejewicz 2020). Therefore, ammonia resulted from agricultural activity is highly potential to contribute to air pollution.

Based on their adaptation ability to the deposition level and the availability of atmospheric nitrogen, lichens can be grouped into three types: oligotrophs, mesotrophs, and eutrophs. Oligotrophs are lichens that grow only in nutrient-poor environments, mesotrophs have intermediate nutrient requirements, and eutrophs are lichens that thrive in nutrient-rich environments (McCune & Geiser 2009).

Oligotrophs are most abundant in areas with average N deposition of 0.5 - 4.2 kg N/ha/year and become less abundant as N deposition increases above 4.2 kg N/ha/year, mesotrophic lichens prefer areas with N deposition of 4.2 - 8.0 kg N/ha/year, and eutrophic lichens can tolerate N deposition up to 8.0 kg N/ha/year (USFS 2025).

Eutrophic lichens species are also known as nitrophilus species which are characterized by being nitrogen-tolerant species that benefit from nitrogen eutrophication (Zarabska-Bożejewicz 2020). This categorization is generally applied to the macrolichens group, which consists of foliose, fruticose, and larger squamulose lichens (McCune & Geiser 2009). Macrolichens are often used as bioindicator species for air quality due to their large surface area, easiness for observation, and greater sensitivity than microlichens, such as crustose lichens (Pasaribu *et al.* 2023).

In the study area, a total of 17 macrolichens species were found (Table 2). There were six eutrophic lichens species, four of which were found at both stations (*Flavoparmelia caperata*, *Parmotrema perlatum*, *Punctelia perreticulata*, *Ramalina fraxinea*), and two species were found at only one each at one of the stations (*Usnea subfloridana* at Station I and *Parmotrema xanthinum* at Station II). As for mesotrophic and oligotrophic lichens species, a total of six species were found. Out of six species, five of them were found only at Station II (*Collema subflaccidum*, *Physcia adscendens*, *Physcia stellaris*, *Hypotrachyna revoluta*, *Parmeliopsis ambigua*), and there was only one species found at Station I (*Usnea glabrescens*).

Our study showed that there were differences in lichens composition between the two research stations. These results suggested that there was a decrease in the diversity of non-nitrophilic lichens species at Station I, which was thought to be caused by high nitrogen emissions from agricultural activities. However, further research is needed to confirm this finding.

Table 2 Macrolichens found at the research site and their nitrogen-sensitivity

No.	Species	Growth forms	Category	Location	
				Station I	Station II
1	*Collema subflaccidum*	Foliose	Oligotroph[a]	-	✓
2	*Heterodermia diademata*	Foliose	Unknown	✓	✓
3	*Physcia adscendens*	Foliose	Mesotroph[a]	-	✓
4	*Physcia sorediosa*	Foliose	Unknown	✓	-
5	*Physcia stellaris*	Foliose	Mesotroph[b]	-	✓
6	*Hypotrachyna afrorevoluta*	Foliose	Unknown	✓	-
7	*Hypotrachyna britannica*	Foliose	Unknown	-	✓
8	*Hypotrachyna revoluta*	Foliose	Oligotroph[a]	-	✓
9	*Flavoparmelia caperata*	Foliose	Eutroph[a]	✓	✓
10	*Parmelina tiliacea*	Foliose	Unknown	✓	-
11	*Parmeliopsis ambigua*	Foliose	Oligotroph[b]	-	✓
12	*Parmotrema perlatum*	Foliose	Eutroph[a]	✓	✓
13	*Parmotrema xanthinum*	Foliose	Eutroph[a]	-	✓
14	*Punctelia perreticulata*	Foliose	Eutroph[b]	✓	✓
15	*Ramalina fraxinea*	Fruticose	Eutroph[c]	✓	✓
16	*Usnea glabrescens*	Fruticose	Mesotroph[a]	✓	-
17	*Usnea subfloridana*	Fruticose	Eutroph[b]	✓	-

Nitrophilus species were mostly found at both stations, Station I and II. This result indicated that both stations had high atmospheric nitrogen deposition. The high nitrogen deposition may have been caused by agricultural activities in the vicinity of the research site.

Conversely, nitrogen levels at Station II may tend to be lower than at Station I, which was indicated by the presence of oligotrophic and mesotrophic lichens species at Station II, such as *Collema subflaccidum*, *Physcia adscendens*, *Physcia stellaris*, *Hypotrachyna revoluta*, and *Parmeliopsis ambigua* (Fig. 3). These species were only found at Station II, so it is noteworthy that some of these species were used as bioindicator species in this study. Of the five species, *Physcia stellaris* (Fig. 3c) was the species having the highest IVI value of 12.42% (Table 1), making it the strongest candidate for bioindicator species in this study. *Physcia stellaris* was also used as a bioindicator species in a study by Susan *et al.* (2017) in the Midwest area of the United States to investigate the levels of contaminant elements in the area.

Thallus morphology of the lichens found at the research site can be categorized into 3 types, namely crustose, foliose and fruticose. Crustose lichens have thallus morphology such as a layer of crust that lives firmly attached to the surface of the substrate. Foliose lichens have a leaf-like thallus morphology, composed of thallus that will develop into lobes, and are equipped with rhizine structures functioning as attachment and food absorption apparatus. Fruticose lichens have a shrub-like thallus morphology with ribbon-like branches (Muvidha 2020; Untari 2024).

In Stations I and II, crustose lichens were found to be the most dominant category, followed by foliose and fruticose lichens (Fig. 4). Crustose lichens are the most resistant to environmental influences because they require less water and can store water optimally due to their strong attachment to the substrate (Pasaribu *et al.* 2002). The strong and tight attachment also makes crustose lichens resistant to environmental stresses, such as temperature, drought, UV radiation, pollution and herbivores (Pasaribu *et al.* 2023). Foliose and fruticose lichens are more susceptible to environmental stresses. Foliose lichens can only be found under certain environmental conditions, for example in still natural habitats (Pasaribu *et al.* 2023). On the other hand, fruticose lichens are the most sensitive to environmental conditions, including air pollution (Roziaty 2016). A study by Sujetoviene (2017) showed that foliose and fruticose lichens are commonly found in areas with low levels of pollution, while crustose lichens are found in areas with high levels of pollution.

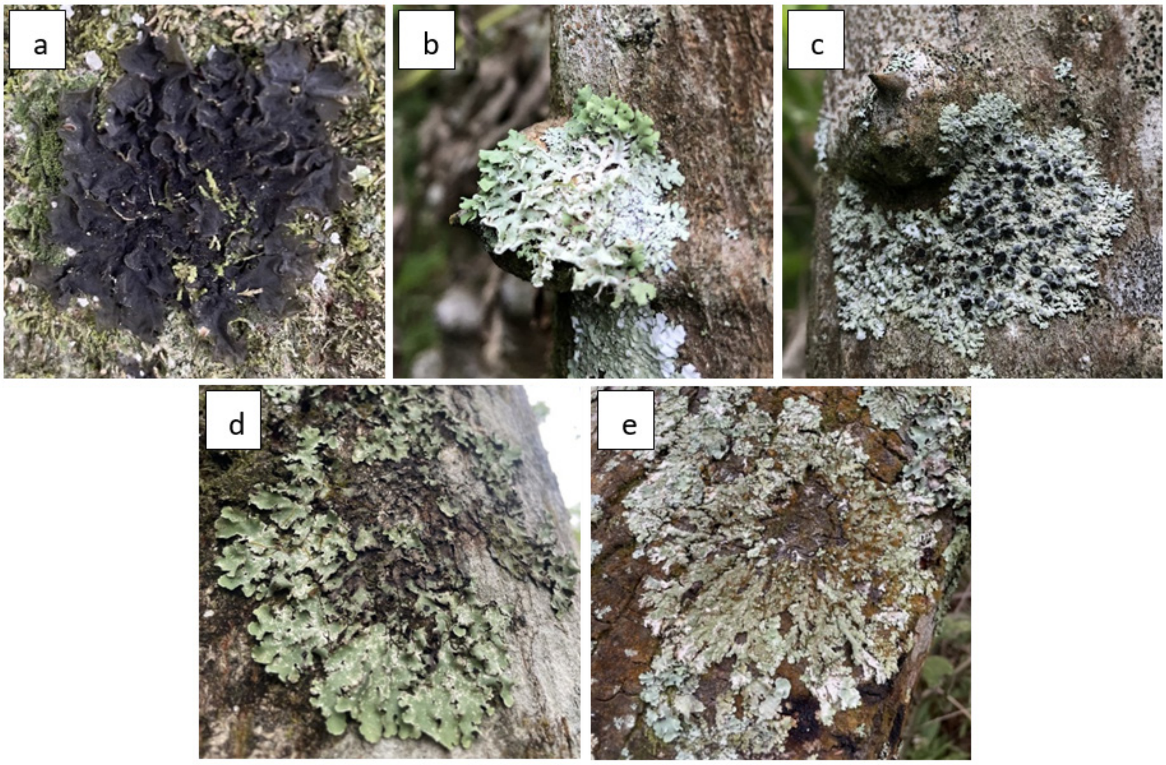

Figure 3 Oligotrophic and mesotrophic macrolichens found at station II
Notes: a = *Collema subflaccidum*; b = *Physcia adscendens*; c = *Physcia stellaris*; d = *Hypotrachyna revoluta*; and e = *Parmeliopsis ambigua*.

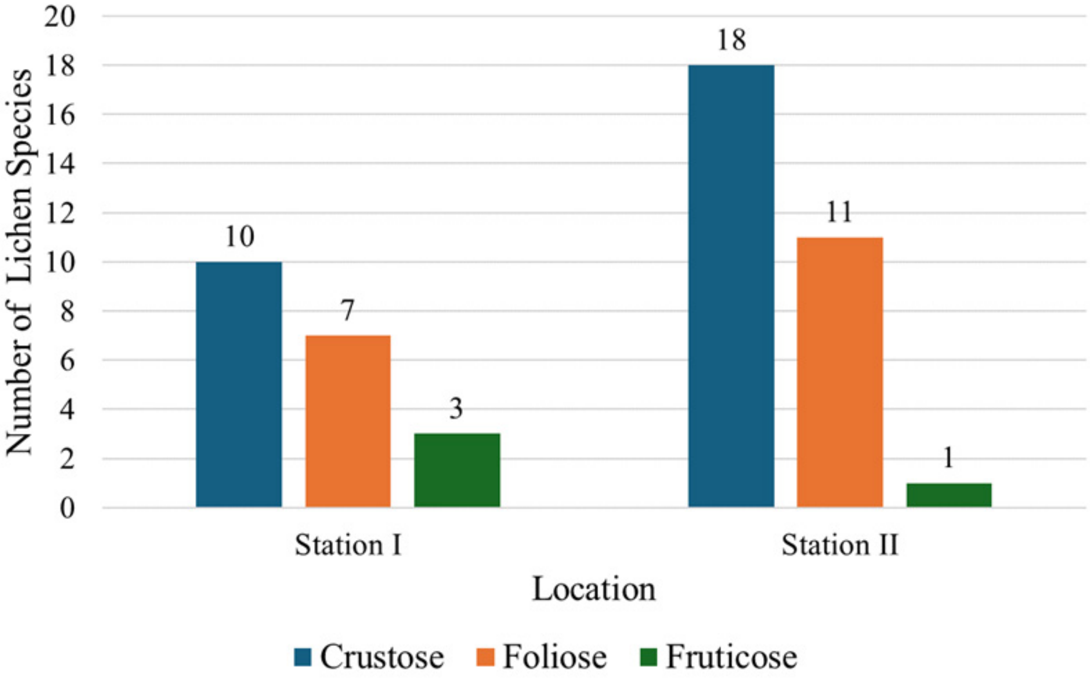

Figure 4 Thallus morphology and number of lichens species

Table 3 Host trees variation and number of lichens individuals encountered

Host tree	Local name	Number of lichens individuals	
		Station I	Station II
Pinus merkusii Jungh. & de Vriese	Pinus	12	8
Altingia excelsa Noronha	Rasamala	4	0
Engelhardtia spicata Lechen ex Blume	Klewer	13	38
Syzygium cumini (L.) Skeels	Duwet	1	0
Glochidion arborescens Blume	Dempul	3	4
Erythrina lithosperma Blume	Dadap Duri	7	13
Aglaia odoratissima Blume	Pancal Kijang	5	0
Symplocos javanica Kurz	Ladok	2	0
Casuarina junghuhniana Miq.	Cemara Gunung	2	0
Lithocarpus elegans (Blume) Hatus.	Pasang	1	1
Castanopsis argentea (Blume) A.DC.	Sarangan	1	4
Schima wallichii (DC.) Korth.	Puspa	0	3
Acacia decurrens Willd.	Akasia	0	3

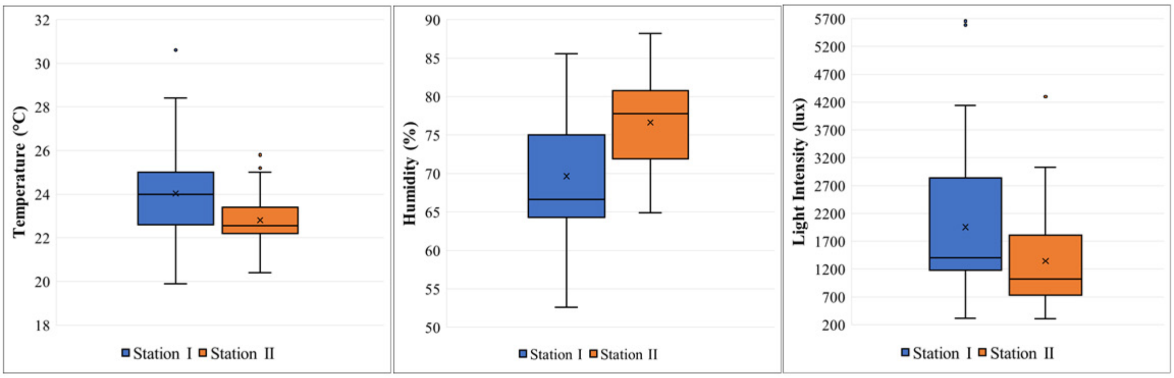

Figure 5 Environmental parameter measurement in the study area

Note: The cross mark shows the average value of each parameter.

The most abundant lichens found at Stations I and II was lichens attached to Klewer tree (*Engelhardtia spicata*) with a total of 51 occurrences (Table 3). The bark type of Klewer tree which is classified as rough with furrows of < 1 cm in size seems to be an easier substrate for lichens to grow on compared to other trees having a smoother bark type. Lichens propagules are more easily trapped and grow on trees having rough bark-texture with shallow and small furrows (Susilawati & Kasiamdari 2021). Bark type with deep cracks causes the bark to be unstable and fragile, so that it peels off easily, for example in *Pinus merkusii* (Susilawati & Kasiamdari 2021). However, our study demonstrated a relatively high prevalence of lichens growing on the bark of *Pinus merkusii* tree (12 thalli at Station I and 8 thalli at Station II).

This finding suggested that bark exfoliation may impede lichens growth, yet it does not entirely preclude it. This phenomenon can be attributed to the fact that deep cracks in the bark are capable of maintaining adequate moisture levels in the substrate, thereby facilitating the penetration of rhizines in foliose lichen (Susilawati & Kasiamdari 2021). This, in turn, provides a foundation for the growth of crustose, foliose, and fruticose lichens.

Lichens diversity and abundance are influenced by environmental parameters, such as air temperature, humidity, light intensity, and nutrients in the place where lichens live (Pasaribu *et al.* 2023). Our study observed that Station I had a higher range of air temperature (19.9 - 30.6 °C) with an average of 24.0 °C, while Station II had a lower range of air temperature (20.4 - 25.8 °C) with an average of 22.8 °C (Fig. 5).

According to Murningsih & Mafaza (2016), the optimal temperature for lichens growth is below 40 °C. Air temperature above 45 °C can damage the chlorophyll pigment contained in the lichens, thus disrupting the photosynthetic process of the lichens. Nonetheless, the mean air temperature measurements obtained from Stations I and II in our study were consistently lower than the maximum temperature threshold that could be tolerated by lichens.

Humidity is one of the factors that greatly affects the ability of lichens to absorb water, nutrients and pollutants contained in the air (Murningsih & Mafaza 2016). Sundberg *et al.* (1996) stated that lichens can still grow and photosynthesize in habitat conditions classified as very humid, with humidity reaching 85%. Humidity more than 85% can reduce the efficiency of lichens photosynthesis by 35 - 49% (Hadiyati *et al.* 2017). Station I exhibited a lower range of humidity, ranging from 52.6 - 85.6% with an average of 69.66%, while station II demonstrated a higher range, ranging from 64.9 - 88.2% with an average of 76.65% (Fig. 5). The humidity measurements between the two stations showed an average humidity that is below the maximum tolerance of lichens. However, Station II relatively had a consistent higher humidity that influence lichens growth.

Light intensity is the factor influencing the ability of lichens phycobionts to perform photosynthesis. Lichens require the lowest light intensity of 1,025 lux to be able to photosynthesize (Murningsih & Mafaza 2016). Station I exhibited a higher range of light intensity (313 - 5,655 lux) with an average of 1,956.8 lux, while station II demonstrated a lower range (306 - 4,297 lux) with an average of 1,343.20 lux (Fig. 5). This finding indicated that the average light intensity at these two stations exceeded the minimum tolerance level of the lichens. The relationship between nitrogen-sensitivity and lichens species suggested that the lichens species found in our study are more likely to be well-adapted to habitats with higher levels of sun exposure (Zarabska-Bożejewicz 2020). Therefore, conditions involving lower humidity, higher temperatures and higher light availability may be beneficial for nitrophilic lichens species and limit the growth of non-nitrophilic species (Pinho *et al.* 2012).

The disparities in air temperature, humidity, and light intensity measurements between the two research stations can be attributed to the distinct vegetation composition observed at each location. Station II had vegetation with higher tree density and denser canopy cover, resulting in lower light intensity, lower air temperature, and higher air humidity. According to Yulianti (2022), areas with open canopies are known to produce higher light intensity, higher air temperature, and lower air humidity, which in turn affects lichens richness. Furthermore, the disparity in environmental parameters between the two stations can be attributed to altitude differences. Higher altitude is associated with lower temperatures and higher relative humidity. Research of Ismail *et al.* (2024) on lichens diversity and richness across varying altitudes indicated that higher elevations are more conducive to lichens growth, owing to the fact that low temperatures and high humidity prevent desiccation.

CONCLUSION

The diversity of lichens species found in the study area consists of 36 species from 13 different families. Lichens composition at the two stations differs, indicating disparities in air quality between the two stations. Station II (1,600 – 1,700 masl) exhibited indications of better air quality in comparison to Station I (1,500 – 1,600 masl), which was distinguished by a higher diversity index value, as well as a greater lichens thallus coverage area. The difference in air quality between the two research stations may have been caused by nitrogen emissions from agricultural activities that limit the diversity and abundance of non-nitrophilic lichens species. Lichens species diversity and abundance are influenced by environmental factors, such as air temperature, humidity, light intensity and host tree bark type.

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